AD-A054 026

AUTOMATIC CONTROL OF WELD PENETRATION

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February 1978

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER AMMRC TR 78-6	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AUTOMATIC CONTROL OF WELD PENETRATION		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Donald C. Buffum		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Army Materials and Mechanics Research Center Watertown, Massachusetts 02172 DRXMR-ER		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A Project: 4764585 AMCMS Code: 3197.6d.4585
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Materiel Development and Readiness Command, Alexandria, Virginia 22333		12. REPORT DATE February 1978 13. NUMBER OF PAGES 8
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Welding
Gas tungsten arc welding
Penetration control

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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ABSTRACT

The objective of this project was to incorporate an infrared thermal probe with the previously developed weld penetration controller to improve penetration control of welds in 3/8"-thick ESR 4340 armor. The weld penetration control system works satisfactorily and reproducibly. The welding process used was gas tungsten arc.

INTRODUCTION

In the welding of steel armor plates complete penetration of the weld bead is one of the requirements. There are several nondestructive methods to determine whether or not full penetration has been obtained after the weld is made. However, a device to control welding variables during the welding of a joint that would insure full penetration welds would save time, materials, and money.

Several years ago a device was developed with MM&T funds on contract DAAG46-71-C-0129 to control weld penetration. This device used the temperature of the base plate in the vicinity of the arc as the controlling factor. The sensing element used to obtain this temperature was an iron-constantan thermocouple that glided along the surface of the plate. During the application of this system two items were noted that caused the unit to work inefficiently. First, certain irregularities in the surface of the plate would cause the thermocouple to bounce and thus feed back an erroneous signal which caused surges in the power input to the arc. Second, as evaluation of the equipment progressed it was found that the thermocouple had to be moved closer to the arc than first planned. The heat of the arc caused the thermocouple to soften and bend. As it bent it shifted the point of temperature reference on the plate away from the arc. This gave a temperature measurement from a different and usually cooler reference point and therefore fed erroneous signals into the control unit.

Since the completion of that earlier work, industry has marketed an infrared temperature measuring device. In using such a device, it was conceived that it would be an ideal unit to work with the penetration controller in place of the thermocouple.

The objective of this project is to unite three pieces of equipment: a feedback-controlled welder, a weld penetration controller, and an infrared temperature measuring device for the control of weld penetration; and evaluate the systems operation of 3/8"-thick steel armor plate.

MATERIALS AND PROCEDURES

Electroslag-remelted (ESR) 4340 steel armor, 3/8" thick, was welded with AX140 filler wire of 0.045" diameter. The composition of the materials is as follows:

	Elements (weight percent)							
Materials	C	Mn	P	S	Si	Ni	Cr	Mo
ESR 4340	0.38	0.74	0.007	0.005	0.22	1.90	0.79	0.25
AX140	0.07-0.11	1.7-2.0	-	-	0.25-0.45	2.0-2.5	0.85-1.2	0.5-0.6

The ESR 4340 plate was received in the heat-treated condition with a Rockwell C hardness of 54. Because of its hardness it was difficult to machine the bevel on the edge of the plate for welding. To reduce time and costs the plates were annealed at 1500 F for one hour and air cooled in preparation for machining and welding.

The initial test welds made with the above materials produced centerline cracks. To eliminate these, the plates were preheated to a temperature of 325 F ± 25 F prior to welding, using a backup plate that incorporated resistance heating elements. The weldments were made in three passes using the gas tungsten arc welding (GTAW) process. The final welding variables used were as follows:

	Passes	
	1	2 and 3
Wire Feed Speed, in./min	100	100
Electrode Composition	2% thoriated tungsten	
Electrode Diameter, in.	0.125	0.125
Volts	11	13
Amperes*	300	330
Travel Speed, in./min	4	4
Gas	argon	argon
Gas Flow, cu ft/hr	50	50
Plate Preheat Temp, deg F	325 ± 25	325 ± 25
Penetration Controller Settings		
Null	5.5	8.0
Sensitivity	80.0	80.0

*The weld penetration controller regulated the amperage over a range of ± 20% of the initial setting. The values given are the initial settings used in the final operation.

The weld penetration controller is designed to operate with both GTAW and GMAW (gas metal arc welding). The funding for the program allowed only evaluation of the GTAW phase.

After heat treating as indicated previously, the plate was prepared for welding by cutting it into 4" x 12" sections. The 12"-long sides of each section were beveled to an included angle of 60°. Initially there was no land,* but later, as discussed in this report, a 1/16" land was used. In order to maintain a uniform surface on each weld pass, the plates were sandblasted prior to welding and between each pass.

DISCUSSION

The first step in the performance of this program was to make the necessary changes in the weld penetration controller so that it would function with the

*That portion of the groove face adjacent to the root of the joint.

infrared thermal probe in place of the iron-constantan thermocouple. These changes were made by the contractor who originally designed and built the controller.

During the initial operation of the completed assembly, there were two major problems. First, there was erratic behavior of the equipment resulting in the burnout of electronic components of the feedback-controlled welder. Second, the temperature measurements made by the infrared temperature probe were far in excess of the known temperature of the point on the plate at which the sensing element was focussed.

The cause of the first problem was traced to two different 110-volt ac power supplies. The voltage for the weld penetration controller is a floating 110 volts received from the feedback-controlled welder. The voltage for the infrared temperature probe and the recording instrument of the weld penetration controller comes from the facility power supply which is 110 volts grounded on one lead. This produced a voltage differential of 40 to 60 volts, causing the difficulty. It was corrected by electrically isolating the components of the infrared temperature probe and the recording instrument and insulating the temperature-sensing element.

The second problem resulted from the fact that the infrared temperature probe was sensitive to visual light. Since the sensing element is focussed on a spot in close proximity to the arc, the light from the arc was picked up by the sensing element and fed into the probe. This produced excessively high temperature readings for the plate. This problem was eliminated by incorporating in the probe a filter which drastically reduced its sensitivity to visual light.

The next step was to determine the point on the plate at which the infrared temperature probe's sensing element would be focussed to obtain a temperature measurement for controlling the operation. Using a heat flow graph from the Welding Handbook,[1] the 1/8"-diameter spot was focussed with its center 0.4" from the centerline of the weld and 0.4" behind the center of the welding electrode.

There are two control potentiometers on the weld penetration controller. The null potentiometer is used to balance the circuit at the temperature selected for control. The sensitivity potentiometer setting determines the response characteristics of the system.

The initial null values were determined by making weld passes on a plate with the weld penetration controller set on standby. The null control was set at the manufacturer's recommended value of 50.0. Welds made with these settings were not satisfactory because the depth of penetration was erratic.

Rykalin's book on heat flow[2] indicated that to control temperature at the initial point of deepest penetration, the point of reference should be 0.3" behind the center of the electrode. He also indicated that a point 0.4" out from the centerline of the weld would produce a desirable temperature range in which to operate. Using the point of reference the null settings were redetermined. Welds were then made with sensitivity settings of 50.0, 80.0, 90.0, and 95.0.

1. *Welding Handbook.* AWS, Miami, Florida, 6th ed., sec. 1, chap. 2, 1968.
2. RYKALIN, N. N. *Calculations of Heat Flow in Welding.* Moscow, U.S.S.R., 1951, translated by Zoi Paley and C. M. Adams, Jr

The settings of 90.0 and 95.0 produced burnthrough from power surges. A sensitivity setting of 80.0 produced satisfactory response and the welds had complete penetration. Several welds made with these settings continued to produce sporadic burnthrough on the first or root pass. In order to eliminate this, a land 1/16" wide was machined on the bottom of each bevel. The included angle of the bevel was kept at 60°.

In setting up the sensing device of the infrared probe, exceedingly great care had to be taken in focussing at the point of reference as small changes in the point of focus in relation to the tungsten electrode brought about large variations in the temperature obtained. These variations were brought about by the steep temperature gradient in the area of the point of reference on the plate. It was believed that the effects of this temperature gradient could be reduced by using a sensing element with a smaller focal spot. To evaluate this theory, a sensing element was obtained with a focal spot diameter of 0.050 inch. This change brought about a high degree of reproducibility and almost perfect penetration control.

With this setup the null settings were redetermined. Null settings of 5.5 for the first pass and 8.0 for the second and third passes, combined with a sensitivity setting of 80.0, produced satisfactory weldments. A series of 12 weldments were made using these settings and visual and radiographic examination indicated all weldments had complete penetration.

Figure 1 is a picture of the overall setup showing the infrared thermal probe control box on the right and the penetration controller on the left. Figure 2 shows a close-up of the welding area with the sensing element of the infrared thermal probe in the center right and the welding gun, wire feeder, and the backup heater in the center. Figure 3 is a replica of the amperage versus time curves made with and without use of the penetration control, the three curves representing the variation in amperage for each of the three passes. During the welding operation the infrared thermal probe recorded the temperature of the reference spot. On the first pass without control (the dotted curve), although there is no fluctuation in the amperage curve, the temperature fluctuated over a range of 250 F; on the second pass this temperature fluctuation was 380 F, and on the third pass 320 F. The three solid curves represent the three passes made to produce the weldments using the controller. The temperature fluctuation during these welds averaged 180 F for the first pass, 90 F for the second pass, and less than 50 F for the third pass. The decrease in fluctuation on the second and third passes is a result of the shorter distance from the reference point to the spot where the arc impinges the plates. The shorter distance was caused by the buildup of the weld bead on each pass, thereby producing a quicker response at the reference point.

In earlier welds, some lack of penetration was noted after the second and third passes. This was eliminated by increasing slightly the null control setting which in turn raised the temperature at which the weld was made by increasing the input amperage.

On selected welds the temperature of the preheat was lowered 50 F. Although good penetration was obtained in the weldments, some porosity was produced.

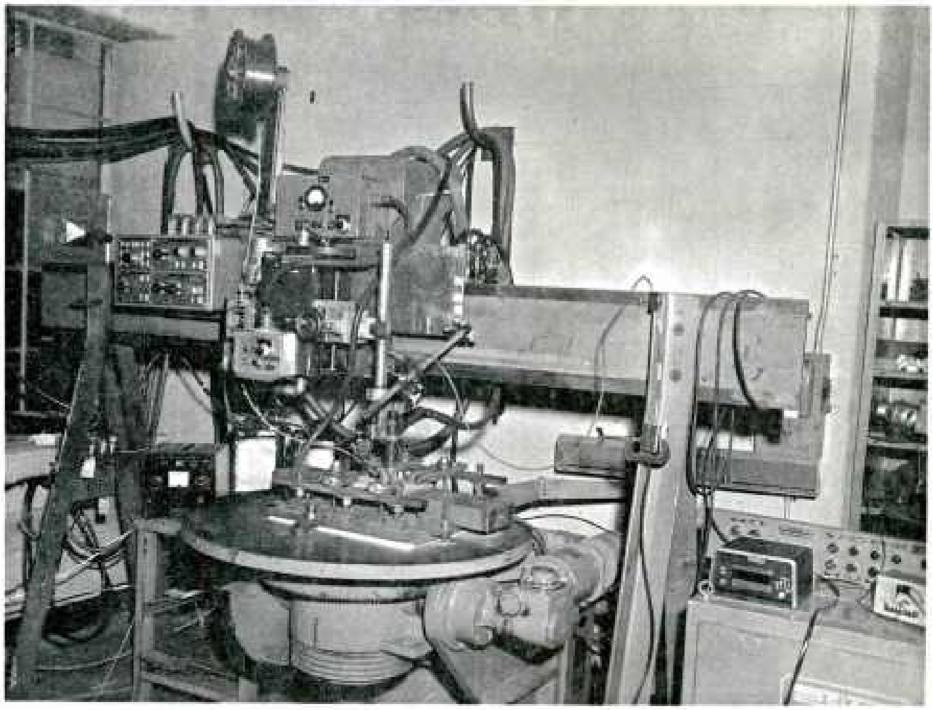

Figure 1. Cverall view of the welding setup for weld penetration control.
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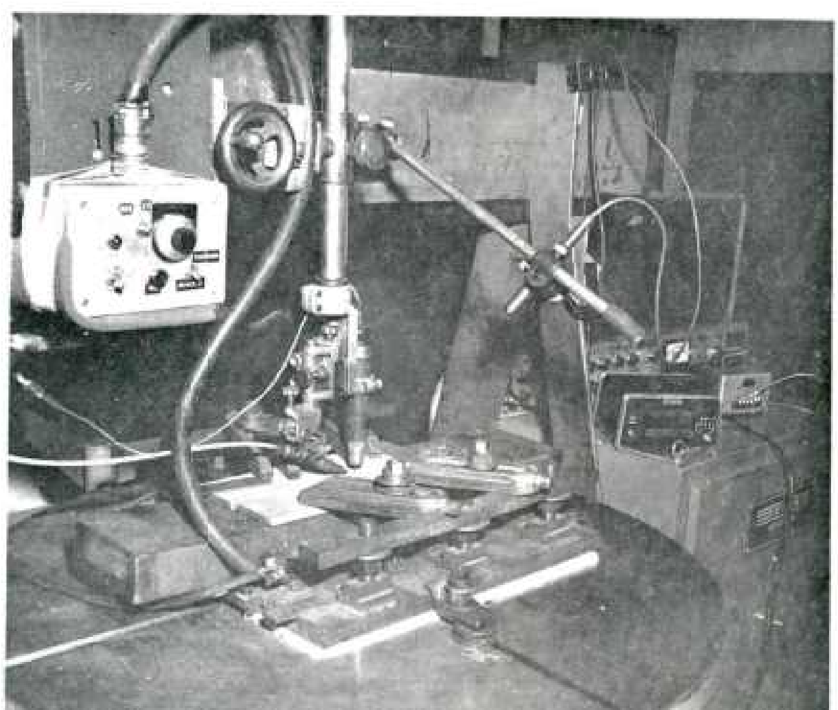

Figure 2. Close-up view of welding area for weld penetration control.
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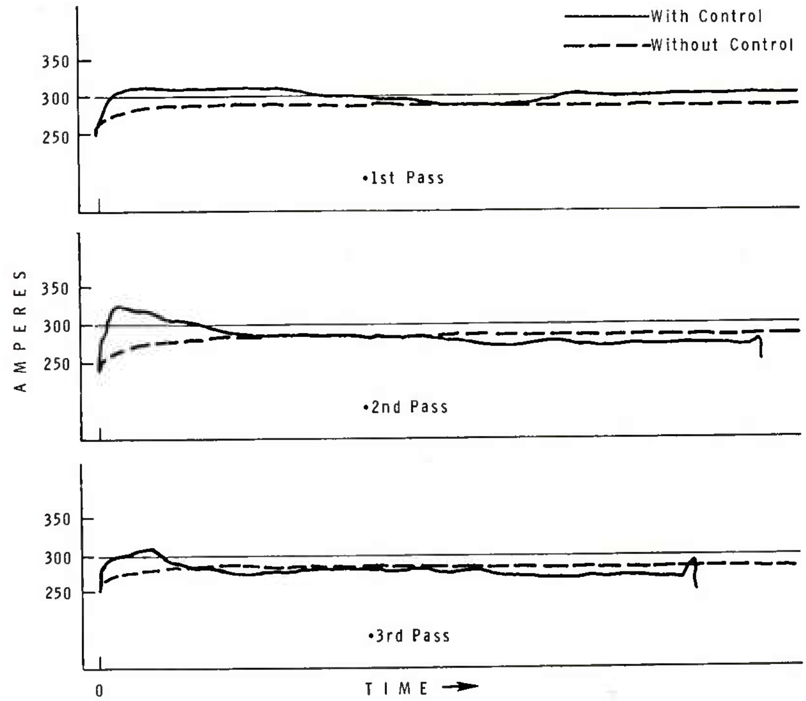

Figure 3. Variation of amperes with time on weld made with and without control.

CONCLUSIONS

Based on the above work, the following conclusions are drawn.

1. The infrared temperature probe was a vast improvement over the thermocouple for measuring the temperature of a spot in close proximity to an arc moving along a plate being welded.

2. The weld penetration controller used in conjunction with the infrared temperature probe can be used to control penetration during welding.

3. Full penetration can be obtained reproducibly using the weld penetration control system.

RECOMMENDATION

It is recommended that additional work be done using the control system with the gas metal arc welding process.

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Technical Report AMMRC TR 78-6, February 1978,
8 pp, illus, D/A Project 4764585,
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